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IMPACT HAZARDS OF THE WATER BALL

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This study was done to determine areas of potential damage hazard as a function of range, velocity, and available energy from impacts by the "water ball," a proposed riot control device. The initial phase of testing established an average velocity decay curve, whereas the major portion of the tests involved shooting human head models and live experimental animals with water balls over a wide range of impact velocities. Levels were determined at which damage to the targets would occur and where it would cease. These levels were then applied to the velocity decay curve to determine the zones of range-related hazard for each of the targets. Three possible zones were

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considered: Zone I, an area of extreme hazard where damage occurred consistently; Zone II, an area of mixed results where damage occurred randomly; and Zone III, an area where no damage to the targets was seen.

Based on the results of this study, assuming that similar damage would occur in a live human, the following conclusions can be reached:

1. Impacts in the head region should be deemed hazardous in varying degrees up to 50 feet (15.2 meters) from the muzzle.

2. Impacts in the liver area should be considered extremely hazardous up to 7 feet (2.1 meters) from the muzzle. Beyond that point, potential damage of varying degrees can be expected at ranges as far from the muzzle as 115 feet (35 meters).

3. Thorax area impacts should not consistently produce lung or heart bruising over the entire range of impact velocities covered in the testing.

4. Any impacts on the eye should be considered potentially hazardous overall.

SUMMARY

The purpose of this study was to determine areas of potential damage hazard as a function of range, velocity, and available energy from impacts by the water ball, a proposed riot control device.

The initial phase of testing consisted of firing a number of water balls across fiducial markers at downrange stations, using special blank launching cartridges and a launch tube clamped to the muzzle of a 12-gauge shotgun. High-speed motion pictures were taken as the balls traveled across the measured distances. The films were analyzed and velocities of the missiles were calculated with the aid of timing marks on the films. The velocities were then used to draw an average velocity decay curve.

The major portion of testing involved shooting human head models (dried human skulls filled and coated with 20% gelatin) and live experimental animals (goats). These anesthetized animals were struck in the liver and lung areas over a range of velocities using both the powder launch and a compressed helium launch technique to determine velocities at which damage to the targets would occur and those at which it would cease. These points were placed on the velocity decay curve to determine the three possible zones of hazards related to distances downrange from the gun muzzle. The zones are: I, an area of extreme hazard where serious damage could always occur; II, an area of mixed results where serious to no damage could be expected; and III, an area where no damage was seen.

Based on the results of this study, assuming that similar damage would occur in a live human, the following conclusions can be reached:

1. Impacts in the head region should be deemed hazardous in varying degrees up to 50 feet (15.2 meters) from the muzzle.

2. Impacts in the liver area should be considered extremely hazardous up to 7 feet (2.1 meters) from the muzzle. Beyond that point, damage of varying degrees can be expected at ranges as far from the muzzle as 115 feet (35 meters).

3. Thorax area impacts should not consistently produce lung or heart bruising over the entire range of impact velocities covered in the testing.

4. Any impacts on the eye should be considered potentially hazardous overall.

PREFACE

The work described in this report was authorized under Task 1J562604A60703a, Wound Ballistics. This work was started in May 1972 and completed in December 1972. The experimental data are contained in notebook MN 2474.

In conducting the research described in this report, the investigators adhered to the "Guide for the Care and Use of Laboratory Animals" as promulgated by the Committee on Revision of the Guide for Laboratory Animals Facilities and Care of the Institute of Laboratory Animal Resources, National Research Council.

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IMPACT HAZARDS OF THE WATER BALL

I. INTRODUCTION.

The water ball is a riot control device designed to produce a deterrent effect through the transfer of a portion of its kinetic energy to a target individual at impact. Other devices of this type have been tested at the Biophysics Division, including the bean bag* and the United Kingdom's rubber baton.* These three studies were supported by the US Army Small Arms Systems Agency, Aberdeen Proving Ground, Maryland.

The water ball is 3 inches in diameter (7.62 cm) and weighs one-half pound (227 grams) when filled with water. The thin-walled shell of the projectile is molded of pliable plastic, scored circumferentially in two planes at 90° to one another. The ball is designed to burst at these weakened score lines as it impacts a target individual, releasing the water fill and dissipating some of the available impact energy. The idea is to decrease the danger of serious damage to the target while delivering a deterrent blow. Furthermore, after the liquid is discharged, the ball cannot be used as a missile by the rioter. Other liquids, such as a dye marker or a foul-smelling substance, might also be used in place of the water fill to add to the effect.

Each of the filled balls is cemented into a light Styrofoam sabot having a 1/4-inch (0.6 cm)-thick disk of Homosote composition board at its base. This unit is muzzle loaded into a rifled launch tube clamped to the barrel of a 12-gauge shotgun. It is then fired, using a special blank launching cartridge. Except for the shotgun, the entire system was obtained through the US Army Small Arms Systems Agency from the manufacturer, Aircraft Armaments Incorporated, Cockeysville, Maryland. The water-ball components and the L110 launcher are shown in figures 1 and 2.

II. EXPERIMENTAL.

A. Part 1. Velocity Decay.

1. Procedure.

The first step in the hazards determination was the establishment of a velocity decay curve. This was done by firing a number of the projectiles at full muzzle velocity across fiducial boards (measured distances) placed at convenient points downrange and recording their flight over these distances on high-speed motion pictures at a frame rate of 1,000 pictures per second. Figure 3 shows the firing setup on the Biophysics Division outdoor range, including the fiducial board near the gun muzzle and the high-speed camera at that station. Two other fiducial boards were placed further downrange at 50 and 75 feet (15 and 23 meters) from the muzzle. The motion pictures were analyzed and velocities at the downrange stations were determined with the aid of timing marks placed on the films at every 1/100 of a second. The mean velocities were plotted against their ranges from the muzzle and a velocity decay curve was drawn through these points. The curve was later used to relate the impact damage which might occur at any particular velocity to the range or distance from the muzzle where that velocity could occur in an actual launch.

2. Results.

The water-ball velocity decay curve is shown in figure 4. Also shown along the curve are the range-related hazard zones for the liver area and head models, which are discussed in parts 2 and 3 of this report. The

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*EB-TR-73056. J. J. Heieck, A. V. Milholland, and A. P. Mickiewicz. Lethality Estimates and Relative Hazards of the 3-inch-Diameter, 0.3-Pound Bean Bag. March 1974. EATR 4657. A. P. Mickiewicz and V. R. Clare. Impact Hazards Study of the United Kingdom 1.5-Inch Rubber Baton (Rubber Bullet) (U). October 1972.

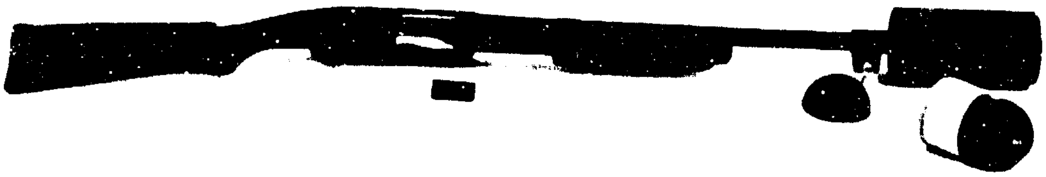

Figure 1. 12-Gauge Shotgun with L-110 Launcher Clamped to Muzzle (Launching Blank and Water Balls in Foreground)

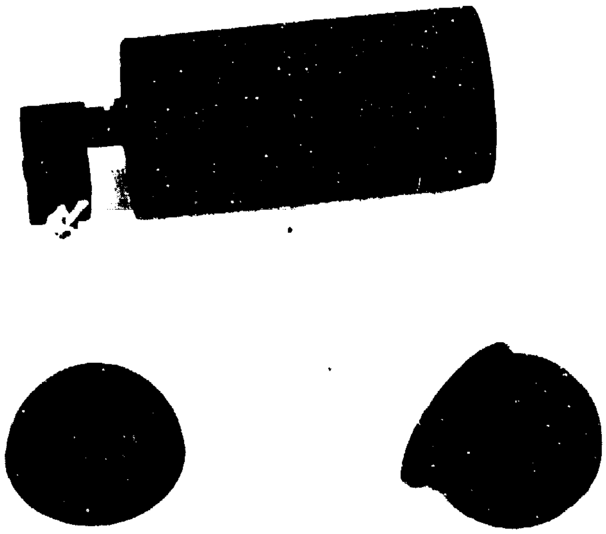

Figure 2. Closeup of Unmounted Launcher and Water Balls

(Note the score lines on the balls.)

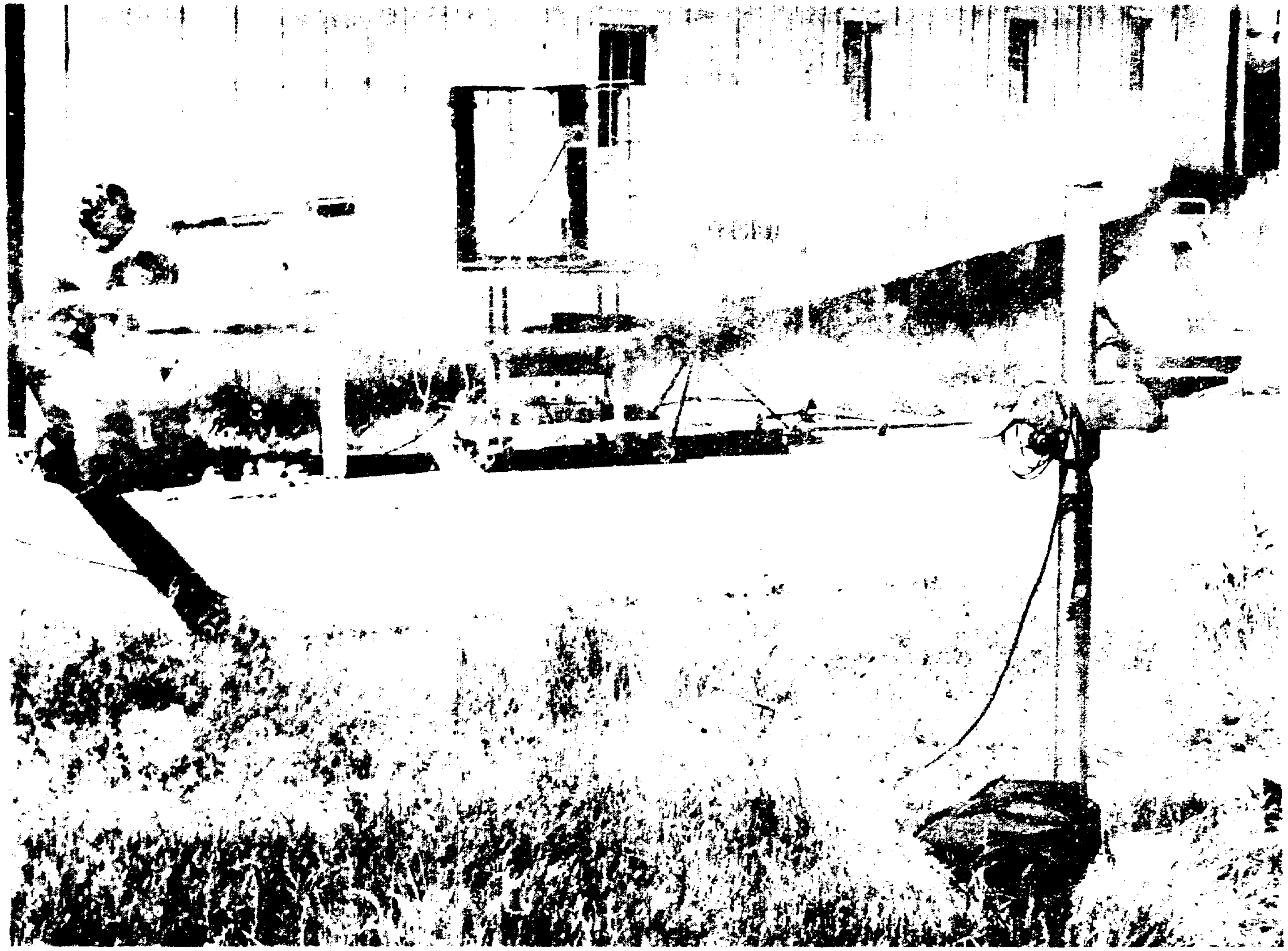

Figure 3. Velocity Determination Setup on Biophysics Division Outdoor Range

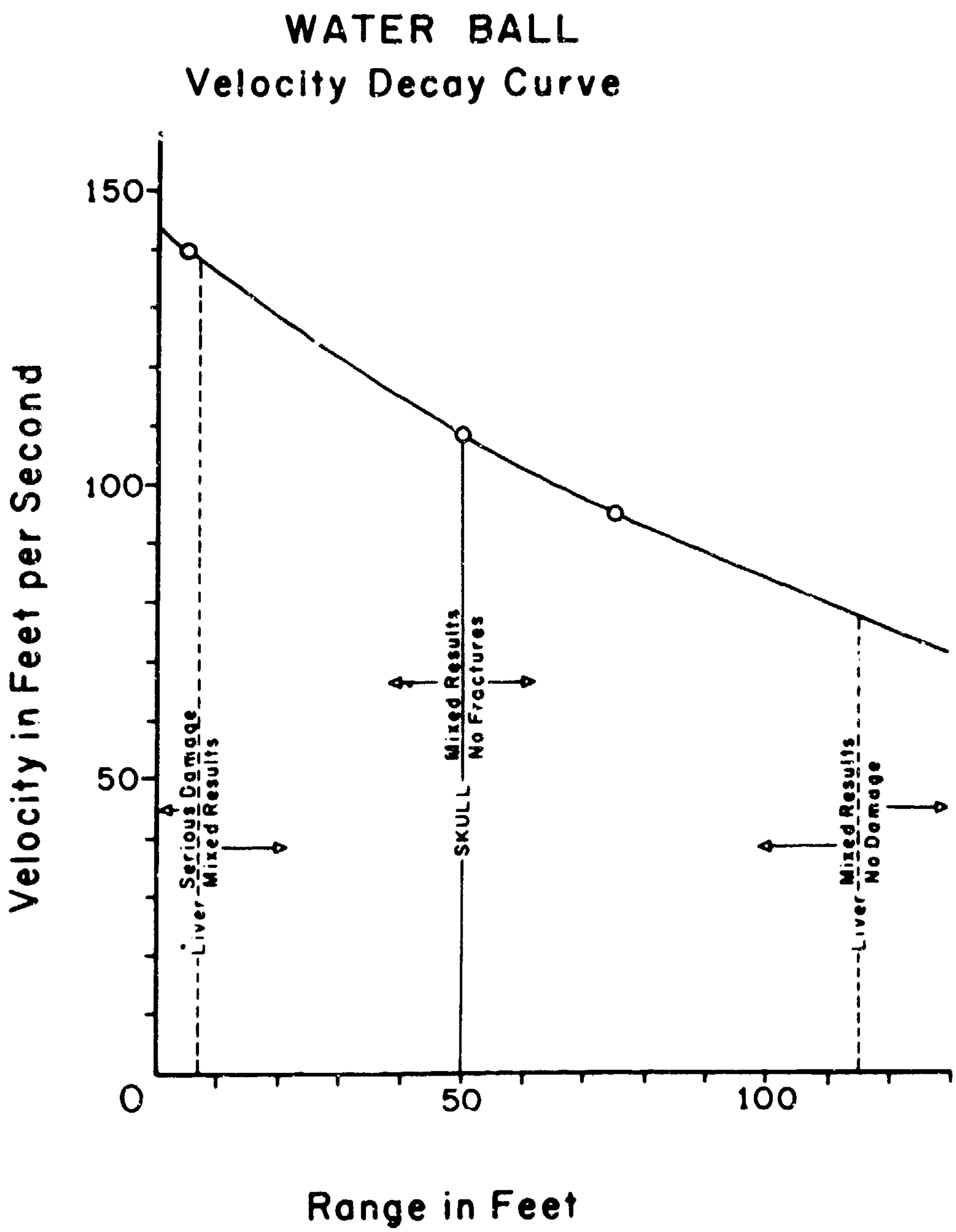

Figure 4. Velocity Decay Curve Showing Range-Related Hazard Zones

zones are: I, an area of extreme hazard where serious damage could always occur; II, an area of mixed results where serious to no damage could be expected; and III, an area where no damage was seen

3. Discussion.

The first attempt at establishing a velocity decay curve for the water ball ended abruptly when the gas deflector in the base of the launch tube was blown out on the 12th shot of the day. The muzzle velocities for these shots varied widely from 97.4 to 228.0 fps (29.7 to 69.5 meters/sec). Five ranged from 123.0 to 154.9 fps (37.5 to 47.2 meters/sec), and three were at 208.0, 216.2, and 228.0 fps (63.4, 65.9, and 69.5 meters/sec). The highest velocity recorded was the one which damaged the launch tube. Assuming that the launcher was brand new when it was received, a total of 39 rounds was fired from it before it failed. It should be noted that only the launching blanks provided by the manufacturer were used. Also, when the velocities began to vary, the launch tube base was examined for obstruction or other conditions which might have explained the erratic results, but nothing unusual was found. Literature from the manufacturer mentions a maximum muzzle velocity up to 160 fps (48.8 meters/sec); for some reason, the three highest velocities recorded were well above this specified range. Perhaps, in these cases, an excessive amount of powder was loaded into the blank cartridges at their time of manufacture. A new launcher was obtained from Aircraft Armaments Incorporated, and the velocity decay shooting was completed without further complications. Sixteen shots were fired; but, in two of these, the ball ruptured in the launch tube as it was expelled and lost water during flight. The Styrofoam sabot is supposed to separate from the ball shortly after it leaves the launch tube; however, this happened in only four of the 16 shots fired. In the remaining cases, the ball and sabot remained together until the unit struck either the side of a fiducial board or the hard macadam surface along the outdoor firing range.

B. Part 2. Human Head Models.

1. Procedure.

The human head models used for this testing consisted of dried human skulls, not degreased, bleached, or fixed in any way, filled and coated with 20% gelatin. The outside coating or "pseudo scalp" was trimmed to approximate the thickness of the scalp and facial tissues of a human head. The "pseudo brain" is the gelatin filling the cranial cavity of the skull. Before shooting, each head model was placed on a die table which was adjusted to the proper height by a gear and chain drive operated by a hand crank. The target was then aimed in horizontally, and a box of cotton waste was placed behind it to keep it from dropping to the floor, since the skull is not tied down and is free to move after the missile impact. No attempt was made to hold the skulls, since any impact damage will occur before they begin to move backward. This can be seen in the high-speed movies which were taken of each impact on these head models. The movies were taken mainly to verify the site of the impact, to see if the sabot had separated, and to make it possible to observe the breakup of the ball and its interaction with the target. Velocities were monitored routinely by firing through light screens on a half-meter baseline. As the light beams were interrupted by the passage of the missiles through them, impulses were sent to counter chronographs to start and stop the digital readouts. The actual velocities were then calculated from these figures. Timing marks on the high-speed films and a fiducial marker in the camera view made it also possible to measure velocity from the camera record if necessary. This was done in one instance when the light screens failed.

Impact velocities were varied using the normal powder launch technique for most of the higher velocities and a compressed helium launch to simulate those lower velocities which would result downrange during an actual launch flight. The targets were placed 10 feet (3 meters) from the muzzle for the higher velocities and 6-3/4 feet (2 meters) away for the lowered velocities. The shots were aimed mainly at the sides of the head models. Three of the head models were struck twice, once on each side, when it was felt that the effects of the first impact would not interfere with those of the second.

After impact, the skulls were dissected and any resulting fractures were measured and photographed. Even those skulls which showed no external evidence of damage were sectioned, since it is possible in such cases to

have a fracture of the inner table only. The velocity-energy levels where damage did or did not occur were then related to a range or distance from the muzzle by referring to the velocity decay curve generated earlier.

2. Results.

Table 1 lists the individual impacts by half-pound water balls on the human head models. They are arranged in descending order of available impact energy expressed both in joules and foot-pounds. A horizontal line is drawn across the table at the point of separation between the mixed results and no damage zones.

In figure 4, the hazard zones for the head model impacts are delineated along the velocity decay curve by a solid vertical line. Only two of the three possible zones are present, one of mixed results (where damage did or did not occur) and another where no fractures resulted. The mixed results occurred at velocities which could be encountered at ranges from muzzle to 50 feet (15.2 meters). At impact velocities which would occur past this range, no damage was produced in the skulls. Of the six fractures which occurred at velocities in the zone of mixed results, two were in the outer table only, whereas the other four involved both tables of the skull. Three of these four, however, were produced in very thin bone, ranging in thickness from less than 0.1 to 0.2 centimeter. Massive comminuted, depressed fracturing occurred only after purposely exceeding 200 fps (61 meters/sec). This is roughly 50 fps above the normal muzzle velocity. A skull struck at this velocity and one damaged at a velocity in the normal range are shown in figure 5 for comparison.

3. Discussion.

Considering the large mass of the water ball with its attendant high impact energy, a surprisingly small amount of damage occurred in the skull targets. The one extremely damaging impact occurred at an excessively high velocity. This was purposely done to establish the upper limit, since a few velocities during the first unsuccessful attempt to establish a decay curve exceeded 200 fps (61 meters/sec). It shows how extremely dangerous this impact energy range can be. Otherwise, the rest of the damage was limited to hairline fractures, some involving only one table of the skull. Two fracture lines were associated with blood vessel canals in the inner table where the bone thickness was only 0.1 to 0.2 centimeter. Due to the large [3-inch (7.62-centimeter)] diameter of the water ball, a wide range of bone thicknesses was involved in many impacts. Bone thickness could range from less than 0.1 to 0.8 centimeter. It appears that the mechanism of energy dissipation through deformation and breakup of the water ball works fairly well against the hard head models. It should be mentioned, however, that there might be a danger of injury to the cervical portion of the spinal column in some cases, because of the large mass of the missile. The head of a live person could be displaced during an impact making "whiplash" a possibility. This study did not address the problem, nor the one of impacts in the eye region. The risk of damage to the orbital contents should be accepted as a definite hazard.

C. Part 3. Live Experimental Animals.

1. Procedure.

The animal chosen for this phase of testing was the castrated male Texas angora goat. This choice was made because the goat is readily available, relatively inexpensive, and has certain internal organs of a size and consistency similar to those of a human. It is, therefore, a good experimental animal to use in both penetrating and nonpenetrating missile studies where organ mass is important.

The animals were prepared by closely clipping the hair on the thorax and abdomen. They were restrained in a special rack, which kept them suspended in front and rear during the impacts. The height of the rack can be adjusted by a built-in hydraulic jack, and the rack is on wheels which are locked in place when it is in the desired position. Sodium pentobarbital was used to anesthetize the goats.

Table 1. Impacts on Human Head Models by Half-Pound Water Balls

Skull number	Velocity		Available impact energy		Bone thickness*	Fracture produced	Remarks
	m/sec	fps	j	ft-lb	cm		
1443	61.4	201.4	427.9	315.8	0.2-0.6	Yes	Massive comminuted, depressed fracture of left side of skull. Cracks extend through left orbit and nasal bones and across the occipital bone.
1443	55.0	180.4	343.3	253.4	0.25-0.45	Yes	Hairline fracture extends superiorly in right parietal bone for 6.8 cm starting at the right sphenoid. Fracture is in outer table only.
1442	46.2	151.6	242.3	178.8	0.25-0.4	Yes	Two hairline fractures extend through both tables of the skull. One is 5.6 cm long in the left parietal bone and the other is 1.5 cm long in the sphenoid bone.
1441	45.1	148.0	230.9	170.4	0.4	No	No damage to skull or gelatin "scalp."
1442	44.5	146.0	224.8	165.9	0.2-0.4	Yes	Hairline fracture 5.0 cm long through right parietal bone.
1441	41.8	137.1	198.3	146.3	0.5	No	Crack in gelatin "scalp" but no damage to bone.
1405	41.6	136.5	196.4	144.9	0.2-0.6	No	Crack in gelatin "scalp" but no damage to bone.
1440	41.3	135.5	193.6	142.9	0.5	No	Laceration of gelatin "scalp"; no damage to bone.
1407	40.3	132.2	184.3	136.0	0.2-0.6	No	No damage to "scalp" or skull.
1440	40.3	132.2	184.3	136.0	0.3	Yes	Hairline fracture of outer table only.
1406	40.1	131.6	182.5	134.7	<0.1	Yes	Small hairline fracture in the floor of the right orbit.
1403	39.0	128.0	172.6	127.4	0.15-0.5	No	Crack in gelatin "scalp" but no damage to bone.
1439	38.4	126.0	167.4	123.5	0.1	Yes	Hairline fracture 3.2 cm long in outer table and 2.4 cm long on inner table, following a thin portion of the parietal bone where a blood vessel canal was located.
1407	37.3	122.4	157.9	116.5	0.2-0.8	No	No damage to "scalp" or skull.
1439	36.4	119.4	150.4	111.0	0.4	Yes	Hairline fracture 1.9 cm long in outer table only of the left parietal bone.

* See end of table for footnote.

Table 1. Contd

Skull number	Velocity		Available impact energy		Bone thickness*	Fracture produced	Remarks
	m/sec	fps	j	ft-lb	cm		
1438	34.2	112.2	132.8	98.0	0.1-0.5	No	No damage to "scalp" or skull.
1437	34.0	111.5	131.2	96.8	0.3-0.5	No	No damage to "scalp" or sku l.
1438	33.7	110.6	128.9	95.1	0.2-0.4	Yes	Two hairline fractures of parietal bone, one 1.8 cm long in outer table only and the other 3.1 cm long in outer table and 1.7 cm long on inner table, running along a vessel canal on inner table where the bone thinned to 0.2 cm.
1437	32.9	107.9	122.9	90.7	0.1-0.8	No	No damage to "scalp" or skull.
1437	31.8	104.3	114.8	84.7	0.15-0.5	No	No damage to "scalp" or skull.
1436	29.6	97.1	99.4	73.4	0.15-0.35	No	No damage to "scalp" or skull.
1436	26.8	87.9	81.5	60.1	0.15-0.45	No	No damage to "scalp" or skull.
1435	21.3	69.9	51.5	38.0	0.1-0.4	No	No damage to "scalp" or skull.
1435	20.7	67.9	48.6	35.9	0.1-0.5	No	No damage to "scalp" or skull.

* Range at area of impact of water ball.

Figure 5 Water-Ball Impact Damage to Human Head Models

A Human skull (head model) struck at 61.4 meters/sec (427.9 joules of impact energy)

B Human skull (head model) struck at 46.2 meters/sec (242.3 joules of impact energy)

The two target areas chosen were the lung and the liver. In some cases, both areas were struck on a single animal, usually the liver on the right and the lung on the left. These were done at velocity levels where it was felt that the effects of the second shot would not interfere with those of the first. The majority of the goats received single impacts, however, and only six of 31 animals were struck twice. Most of the animals were kept approximately 1 to 3 hours, with five of them remaining overnight until sacrifice.

Wound dissections were performed on the sacrificed animals and damage was measured and photographed, especially that which was discovered in the internal organs. Internal blood loss was measured and the tissue thickness in the body wall overlying the organs was recorded.

The results of impacts in the two areas were put in tabular form in descending order of available impact energy, and hazard zones were delineated for each of them.

2. Results.

a. Liver-Area Impacts.

Fourteen impacts by water balls were on the liver. Impact velocities ranged from 63.6 to 148.9 fps (19.4 to 45.4 meters/sec), with available energies of from 31.5 to 172.6 foot-pounds (42.7 to 233.9 joules). Damage to the liver resulted consistently down to 137.5 fps (41.9 meters/sec) and 147.1 foot-pounds (199.3 joules) of energy. Mixed results occurred between 99.4 and 122.4 fps (30.3 and 37.3 meters/sec) or 76.9 to 116.5 foot-pounds (104.2 to 157.9 joules). At 76.8 fps (23.4 meters/sec) and below, no damage to the liver resulted. Table 2 lists data for the individual impacts. Horizontal lines are drawn across the table at the points of separation of the three hazard zones. These zones are also shown in figure 4 and are represented by the broken vertical lines drawn at separation points along the velocity decay curve.

The extremely hazardous zone is very narrow, extending from the muzzle to 7 feet (2.1 meters) away. The zone of mixed results, however, is very wide, extending from 7 feet all the way to 115 feet (35 meters) from the gun muzzle. Past this relative range, no liver damage was produced. Figure 6 shows the liver from goat No. 19813 struck by a water ball at 137.5 fps (41.9 meters/sec) and 147.1 foot-pounds (199.3 joules) of energy within the zone of extreme hazard. Lateral and medial views are presented to show the extent of the fractures on these surfaces. A cross section through the damaged area is also shown, illustrating that the fractures extend through the full thickness of the lobe. This animal, which survived a 2-hour holding period, had severe hemorrhage from these fractures amounting to 925 milliliters of blood. This is approximately 37% of the total blood volume in this goat, and it was the largest blood loss seen in the extremely hazardous velocity range. Four other animals struck at velocities in this range also had significant blood loss from their liver wounds of from 100 to 200 milliliters.

In the zone of mixed results, one animal struck in the liver area at 115.5 fps (35.2 meters/sec) and 103.8 foot-pounds (140.6 joules) of energy lost 125 milliliters of blood from serious cracks present only on the medial liver surface. This was the only instance of significant blood loss in this hazard zone.

b. Lung-Area Impacts.

Twenty-one impacts by water balls were on the thorax. Impact velocities ranged from 35.7 to 149.9 fps (10.9 to 45.7 meters/sec) with available impact energies from 13.7 to 237.0 joules (10.1 to 174.9 foot-pounds). Damage to the lungs did not consistently occur, even at the higher velocities, so the zone of mixed results encompasses the entire range of velocities encountered along the decay curve. For this reason, no hazard zones for the lung area are delineated in figure 4 along the velocity decay curve.

Table 3 lists data for the individual impacts on the goat thorax. Damage to the lungs was limited to bruising with only one small laceration, 0.7 cm long, occurring at approximately 118.8 fps (36.2 meters/sec) and 148.7 joules (109.7 foot-pounds) of impact energy. No rib fractures were produced. In 11 of the 21 impacts, no damage resulted in the lungs; however, five instances of superficial hemorrhage in the heart were seen. Three of these

Table 2. Impacts on the Liver Areas of Goats by Half-Pound Water Balls

Animal number	Body weight	Velocity		Available impact energy		Damage produced	Remarks
	kg	m/sec	fps	j	ft-lb		
19733	43.0	45.4	148.9	233.9	172.6	Yes	Internal liver fractures; capsule is intact.
19731	54.8	44.0	144.4	219.7	162.1	Yes	Serious liver fractures extend through capsule; 175-ml internal blood loss.
19815	37.3	44.0	144.4	219.7	162.1	Yes	Small liver fracture and hematoma under capsule.
19812	45.4	42.9	140.8	208.9	154.2	Yes	Three small fractures on medial surface of liver with a subcapsular hematoma; 200-ml internal blood loss.
19814	58.2	42.3	138.9	203.1	149.9	Yes	Four small fractures on medial surface of liver; 100-ml internal blood loss.
19813	34.6	41.9	137.5	199.3	147.1	Yes	Very serious fractures extend through the liver; 925-ml internal blood loss.
19804	45.7	41.9	137.5	199.3	147.1	Yes	Serious fractures on medial surface of liver - subcapsular hematomas on lateral surface; 125-ml internal blood loss.
19729	37.8	37.3	122.4	157.9	116.5	Yes	Fracture within liver; capsule is intact.
19819	41.4	36.3	119.2	149.6	110.4	No	
19818	34.9	35.2	115.5	140.6	103.8	Yes	Serious liver fractures on medial surface only; 125-ml internal blood loss.
19829	41.3	32.9	107.9	122.8	90.6	No	
19828	41.5	30.3	99.4	104.2	76.9	Yes	Small tear is present between liver lobes.
19827	60.0	23.4	76.8	62.1	45.8	No	
19826	37.0	19.4	63.6	42.7	31.5	No	

Figure 6. Water-Ball Impact Damage to a Goat Liver

(Liver struck by a water ball at 41.9 meters/sec and 199.3 joules of impact energy)

A. Lateral surface
B. Medial surface
C. Cross section

Table 3. Impacts on Goat Thorax by Half-Pound Water Balls

Animal number	Body weight	Velocity		Available impact energy		Damage produced	Remarks
	kg	m/sec	fps	j	ft-lb		
19728	48.0	45.7	149.9	237.0	174.9	No	None.
19732	40.0	44.3	145.3	222.7	164.4	No	None.
19733	43.0	41.9	137.5	199.3	147.1	No	None.
19810	35.3	41.9	137.5	199.3	147.1	Yes	Very slight hemorrhage on medial surface only of right lung.
19811	41.9	41.9	137.5	199.3	147.1	No	None.
19813	34.6	41.9	137.5	199.3	147.1	Yes	Diaphragmatic lobe of lung has a 4.0- by 5.5-cm hemorrhage on lateral surface and a 3.0- by 8.0-cm hemorrhage on medial surface. Hemorrhage also found in papillary muscles of the left ventricle in heart.
19807	50.5	41.4	135.8	194.5	143.5	No	Hemorrhage was found in the papillary muscles of left ventricle in the heart.
19803	42.3	41.1	134.8	191.7	141.5	Yes	Moderate hemorrhage in right diaphragmatic lobe.
19809	39.2	41.0	134.5	190.8	140.8	No	None.
19816	37.7	40.9	134.2	189.9	140.1	Yes	Moderate hemorrhage in right diaphragmatic lobe.
19731	54.8	40.4	132.5	185.2	136.7	Yes	Very slight hemorrhage in lung, but hemorrhage was found in the left ventricle wall of the heart.
19730	57.6	40.0	131.2	181.6	134.0	No	None.
19808	39.4	39.3	128.9	175.3	129.4	No	Hemorrhage was found in the interventricular septum and papillary muscles of the left ventricle of the heart.
19805	37.8	39.2	128.6	174.4	128.7	Yes	Hemorrhage was found along the dorsal borders of the right and left lungs.
19729	37.8	36.2	118.8	148.7*	109.7	Yes	Medial surface of right diaphragmatic lobe bruised, with superficial laceration 0.7 cm long present.

* Approximate velocity was used here to calculate energy. Timing marks were missing from high-speed film, and a set frame rate of 3,000 pictures per second was used to determine the missile velocity.

Table 3. Contd

Animal number	Body weight	Velocity		Available impact energy		Damage produced	Remarks
	kg	m/sec	fps	j	ft-lb		
19832	37.0	32.6	107.0	120.6	89.0	No	None.
19830	28.6	31.4	103.0	111.9	82.6	Yes	Moderate hemorrhage in right diaphragmatic lobe only.
19831	51.3	31.2	102.4	110.5	81.5	Yes	Bruising seen along the ventral border of the right diaphragmatic lobe, plus hemorrhage in the left ventricle wall of the heart.
19833	31.7	28.8	94.5	94.1	69.4	Yes	Very slight hemorrhage on diaphragmatic lobe.
19826	37.0	23.8	78.1	64.3	47.4	No	None.
19817	46.0	11.0	35.7	13.7	10.1	No	None.

occurred in the papillary muscles of the left ventricle, and the remaining two were in the wall of the left ventricle. This damage, like that seen in the lungs, did not occur consistently and was found at lower as well as the higher velocity levels. Only a single area of hazard is thus present for the thorax, encompassing a zone of mixed results which extends across the entire range of velocities and includes both lung and heart bruising. Figure 7 shows the lungs from goat No. 19805 struck by a water ball at 128.6 ft/sec (39.2 meters/sec) and 128.7 foot-pounds (174.4 joules) of energy. The lungs are sectioned to show the extent of internal hemorrhage.

None of the animals died of the damage produced by water-ball impacts in the two body areas considered in this study.

3. Discussion.

The results of this study illustrate the basic problems involved in using kinetic energy itself to produce a deterrent effect without causing serious damage. The three sensitive body areas of concern are the head, abdomen, and thorax. They present three different kinds of targets. The head is bony and hard, the abdomen is soft and yielding, wheras the thorax with the rib cage falls somewhere between the other two in its resistance to the impact forces. The water ball is designed to deform and rupture upon impact; however, the rate at which these phenomena occur is directly related to the "hardness" of the target involved and the strength of the shell of the missile itself. Therefore, the bursting action occurs more readily in the head, where compliance between missile and target differ markedly, and the ball can deform and rupture easily.

The abdomen, at the other extreme, is quite soft in relation to the missile and is deformed during impact as the body wall is pressed in and displaced. The water ball here can thus cause fractures in the liver and other friable organs by deforming the body wall to a depth where the tissues of these internal organs are ruptured before the ball can burst and dissipate energy.

The thorax, with its bony rib cage, is much more resistant to deformation than the abdomen but less resistant than the head. This is because the skull deforms within its own elastic limits, acting as a rigid shell for the brain within, and has only a relatively thin layer of soft tissues over it. The thorax, however, is less rigid with ribs and cartilages able to bend, intercostal musculature which can stretch, and articulations which allow further movement of the chest wall. It also has a thicker layer of overlying soft tissues which can greatly affect the application and distribution of an impact force. This is a cushioning effect which tends to slow down the time over which the deformation of the body wall will occur.

No attempt was made to assess concussive effects of impacts to the head or the effects of another type of injury which may be possible with the item, that of "whiplash" (injury of the cervical spine).

III. CONCLUSIONS.

Based on the results of this study, assuming that similar damage would occur in a live human, the following conclusions were reached:

1. Impacts in the head region should be deemed hazardous in varying degrees up to 50 feet (15.2 meters) from the muzzle.

2. Impacts in the liver area should be considered extremely hazardous up to 7 feet (2.1 meters) from the muzzle. Beyond that point, potential damage of varying degrees can be expected as far from the muzzle as 115 feet (35 meters).

3. Thorax area impacts should not consistently produce lung or heart bruising over the entire range of impact velocities covered in the testing.

4. Any impacts on the eyes should be considered potentially hazardous overall.

A

B

Figure 7. Water-Ball Impact Damage to Goat Lungs

(Damage resulting from water-ball impact at 39.2 meters/sec and 174.4 joules of impact energy)

A. **Dorsal borders of lungs showing external appearance.**

B. **Both lungs sectioned showing extent of internal hemorrhage along dorsal borders**